

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
27 December 2001 (27.12.2001)

PCT

(10) International Publication Number
WO 01/99202 A1

- (51) International Patent Classification⁷: **H01L 31/0272**, 31/0352, 31/072 (72) Inventor: **ISHIKAWA, Akira**; 846 FM 2453, Royse City, TX 75189 (US).
- (21) International Application Number: PCT/US01/16581 (74) Agents: **O'DELL, David, M.** et al.; Haynes and Boone, LLP, 901 Main Street, Suite 3100, Dallas, TX 75202 (US).
- (22) International Filing Date: 23 May 2001 (23.05.2001) (81) Designated State (national): JP.
- (25) Filing Language: English (84) Designated States (regional): European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR).
- (26) Publication Language: English
- (30) Priority Data: 09/599,155 21 June 2000 (21.06.2000) US Published:
— with international search report
- (71) Applicant: **BALL SEMICONDUCTOR, INC.** [US/US]; 415 Century Parkway, Allen, TX 75013 (US). For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.



WO 01/99202 A1

(54) Title: **SPHERICAL SHAPED SOLAR CELL FABRICATION AND PANEL ASSEMBLY**

(57) Abstract: A spherical shaped solar diode having an n-type substrate surrounded by a p-type layer of semiconductor material is disclosed. In addition, a plurality of hetero-junction super lattice structures are formed surrounding the p-type layer. The plurality of hetero-junction super lattice structures include alternating layers of Si and SeBeTe. The plurality of hetero-junction super lattice structures adapt the diode to convert higher energy light (as compared to 1.1eV light) to electrical energy. The diodes are formed into a solar panel assembly. The panel assembly includes a wire mesh to secure the diodes and electrically contact one electrode of each diode. A dimpled sheet is also used for securing the diodes and electrically contacting the other electrode of each diode. The diodes are positioned adjacent to the dimpled sheet so that when light is applied to the solar panel assembly, the diodes are exposed to the light on a majority of each diode's surface.

SPHERICAL SHAPED SOLAR CELL FABRICATION AND PANEL ASSEMBLY

Background

The present invention relates generally to semiconductor devices, and more particularly, to a system and method for manufacturing spherical shaped solar cells and arranging the spherical shaped solar shells into a solar panel assembly.

5 A major obstacle forbidding solar energy from being utilized widely is the high manufacturing and material cost for solar cell devices. Typically, as disclosed in US Patent No. 4,691,076, manufacturing conventional solar array involves lengthy processing steps such as expensive multi step melting and solidification process. By using spherical shaped solar diodes, solar arrays will be more cost efficient and more widely used.

10 Spherical shaped solar diodes are relatively known in the art. However, doping a spherical shaped substrate, either with p-type or n-type material, is time consuming since only a slow solid state surface diffusion process is normally used. This prolonged diffusion process adds a significant cost for producing the solar cell diodes, which adds to the overall manufacturing cost. It is desired to provide a relatively quick and inexpensive process for making solar cells.

15 Further, it is a normal practice in the semiconductor industry to manufacture semiconductor devices through batch processing. The transportation time between process locations tends to introduce additional cost and increase possibility of contamination. In order to achieve overall efficiency, thus reducing the corresponding manufacturing cost, a method for producing solar cell devices through an uninterrupted manufacturing stream line is desired.

20 Moreover, it is desired that solar cell devices in general, and solar arrays in particular, be extremely efficient. By making the solar arrays as efficient as possible, their overall acceptance will become even greater. Furthermore, the obvious environmental benefits of solar energy are further enhanced by its gain in popular use.

25 Further still, it is desired to improve the overall operation, quality, and reliability of solar cells in general, as well as the overall solar cell panels.

Summary

30 A technical advance is provided by an improved solar cell and panel assembly. In one embodiment, the solar cell is a spherical shaped solar diode having a first substrate (e.g., n-type) surrounded by a p-type layer of semiconductor material. In addition, a plurality of

hetero-junction super lattice structures are formed surrounding the p-type layer. In some embodiments, the plurality of hetero-junction super lattice structures include alternating layers of Si and SeBeTe. The plurality of hetero-junction super lattice structures adapt the diode to convert higher energy light (as compared to 1.1eV light) to electrical energy.

5 In some embodiments, the panel assembly includes a plurality of solar devices, such as the spherical shaped solar diode discussed above. A wire mesh is used to secure the devices and electrically contact one electrode of each device. A dimpled sheet is also used for securing the devices and electrically contacting the other electrode of each device. The devices are positioned adjacent to the dimpled sheet so that when light is applied to the solar
10 panel assembly, the diodes are exposed to the light on a majority of each diode's surface.

The dimpled sheet may include a plurality of concave dimples, one for each diode. Each concave dimple can individually reflect light to the corresponding diode. Each concave dimple may also include a support structure for positioning each corresponding diode in a central interior portion of the concave dimple. In some embodiments, the concave dimples
15 are formed to protect the corresponding diode from external forces. Also in some embodiments, each concave dimple includes an aperture through which a fluid may flow.

In some embodiments, the dimpled sheet includes a plurality of support dimples for strengthening and supporting the assembly. Each support dimple may also include an aperture through which a fluid may flow.

20 As a result, a highly efficient solar cell device and solar panel assembly is created. In addition, the manufacturing process to create the solar cell device and/or the solar panel assembly is relatively straightforward and inexpensive.

Brief Description of the Drawings

Fig. 1 illustrates one embodiment of a solar device for use in the present disclosure.

25 Figs. 2a, 2b are graphs of electrical operation of the solar device of Fig. 1.

Figs. 3, 3a illustrate another embodiment of a solar device for use in the present disclosure.

Figs. 4a, 4b are graphs of electrical operation of the solar device of Fig. 3.

Figs. 5a, 5b are drawings of processing systems for manufacturing the device of Fig.

30 3.

Fig. 6 is a perspective view of a solar panel assembly according to one embodiment of the present disclosure.

Figs. 7a, 7b, 7c are angular views of the assembly of Fig. 6.

Figs. 8a, 8b, 8c are diagrams of how a solar diode is mounted onto a portion of the assembly of Fig. 6.

Figs. 9-11 illustrate how the solar panel assembly of Fig. 6 can be tested.

5 Description of the Preferred Embodiment

The following disclosure provides many different embodiments, or examples, for implementing different features of the invention. In general, the disclosure can be separated into two sections: spherical shaped solar cell devices and solar panel assemblies. Techniques and requirements that are only specific to certain sections and/or embodiments should not
10 be imported into other embodiments. Also, specific examples of chemicals, components, and processes are described below to help clarify the invention. These are, of course, merely examples and are not intended to limit the invention from that described in the claims.

Spherical Shaped Solar Cell Devices

Referring now to Fig. 1, one embodiment of a spherical shaped solar cell
15 (photovoltaic) device is designated generally with the reference numeral 10. The device 10 includes a p-type silicon single crystal substrate 12 onto which an n-type silicon layer 14 is applied. The fabrication of the p-n junction is key to successful operation of the device 10. Although photovoltaic technologists may use many other varieties of semiconductors, crystalline-silicon concepts represent a typical application for the present disclosure.

20 Referring also to Figs. 2a and 2b, silicon has two distinct energy bands: a lower, valence band and an upper, conduction band. The valence band has available energy states and valence electrons (e.g., an electron 20) and is therefore filled. As shorter wave length light is applied to the device 10, energy is transferred to the valence electrons 20, making it statistically probable that a certain number of the electrons will be raised in energy to such
25 an extent that they are free to conduct electrical charge in the conduction band.

Fig. 2b provides a graph 40 of light energy (measured in wavelength) compared to light intensity. Typically, the device 10 can convert about 1.1 eV of light energy into electricity, at a relatively small wavelength band 42 of light energy.

Referring now to Fig. 3, another embodiment of a spherical shaped solar cell device is
30 designated generally with the reference numeral 50. The device 50 includes a p-type silicon single crystal substrate 52 onto which an n-type silicon layer 54 is applied. A plurality of hetero-junction super lattice structures 56 are then formed on the surface of the n-layer 54.

As shown in blowout Fig. 3a, the hetero-junction super lattice structures 56, in the present embodiment, include a plurality of interchangeable layers of silicon (Si) and beryllium-selenium-tellurium (BeSeTe). The structures 56 are very high quality, having a matched lattice constant and a low interface state density hetero junction between the BeSeTe and the Si. The BeSeTe layer is relatively inexpensive, as compared to conventional III-V compound semiconductors due, in part, to the improved process discussed below. In a preferred embodiment, the BeSeTe is at a ratio of 1:0.55:0.45, although other ratios can be used. Source material for the BeSeTe layers may include:

BeH₂, Be(CH₃)₂, Be(C₂H₅)₂, *etc.*

SeH₂, Se(CH₃)₂, Se(C₂H₅)₂, *etc.*

TeH₂, Te(CH₃)₂, Te(C₂H₅)₂, *etc.*

Source material for the Si layers may include:

SiH₄, Si₂H₆, *etc.*

Referring also to Figs. 4a and 4b, the device 50 has the same two energy bands: the valence band and the conduction band, although the shape of these bands are slightly modified by the structures 56. Fig. 4b provides another graph 90 of light energy (measured in wavelength) compared to light intensity. Typically, the device 10 can mostly convert about 1.1 eV of light energy into electricity, at a relatively large wavelength band 92 of light energy.

As a result, the device 50 can convert higher energy light as well as 1.1 eV light. In addition, the BeSeTe layer enables a lattice matched hetero junction by selecting an appropriate ratio of Se and Te.

Referring now to Fig. 5, the hetero-junction super lattice structures 56 can be manufactured by a series of free fall chemical vapor deposition (CVD) processing tubes 100, 102, 104. These tubes are similar to those described in U.S. Patent 5,955,776, which is hereby incorporated by reference, with changes discussed in greater detail below. In addition, technology described in U.S. Patent 6,053,123, which is also hereby incorporated by reference, may also be implemented in some embodiments.

Each of the processing tubes 100-104 is similarly constructed, with parameters and environments adapted for a particular CVD operation. In the present example, the processing tubes 100, 104 are used for applying BeSeTe through CVD, and tube 102 is used for applying Si through CVD. In some embodiments, there are many more processing tubes

for applying additional layers of BeSeTe and/or Si onto the device 50. It is understood that in the present discussion, the device 50 is being fabricated, and therefore at different times may not yet have all the layers and attributes discussed above with reference to Fig. 3.

Each processing tube 100-104 includes a receiver 110 for connecting to a transfer tube 112. The transfer tube 112 provides the spherical shaped devices 50 from previous operations.

Referring to Fig. 5b, the transfer tube 112 may represent many different transfer mechanisms, including a batch type carrying system. In some embodiments, no transfer tubes may be used. For example, the processing tubes (designated 100', 102', 104') are directly connected to each other and the devices 50 may simply drop or float from one tube to the next.

Referring to Figs. 5a and 5b, the receiver 110 provides the sequence of devices 50 into a processing chamber 120. The processing chamber includes a vaporized interior of the material being processed (Si or BeSeTe). The processing chamber 120 includes a first heated portion 122 and a second cooling portion 124. The heated portion 122 may be heated by an electrical heater, a plasma flame, or any other suitable heating system, represented generally with the reference numeral 125. In one embodiment, a temperature of the heated portion 122 exceeds the melting point of the device 50. Further connected to the cooling portion 124 is a receiver 126 for receiving the device 50 after successful CVD.

In operation, a sequence of the devices 50 move through the receiver 110 and into the heated portion 122 of the chamber 120. The heating system 125 heats and starts to melt the devices 50. Since the devices 50 are moving through the heated portion 122, they do not completely melt. The vaporized material inside the chamber 120 deposits onto the devices 50 and solidifies, as the devices move through the cooling portion 124. The devices 50 are then received in the receiver 126, where they may now proceed to the next processing tube, as required.

Once completed, the devices can be further processed to provide electrodes to both the p-type material and the n-type material. Examples of this further processing are discussed in the following section.

An advantage of the above process is that many spherical solar cells can be rapidly and continually processed in a sequential manner.

Solar Panel Assembly

Referring now to Figs. 6, 7a, 7b, and 7c, one or more of the solar devices, such as the spherical shaped solar diodes 10 and 50 of Figs. 1 and 3, respectively, can be formed into a solar panel assembly 200. The assembly 200 includes a conductive wire mesh portion 210 for securing and electrically contacting the solar devices (e.g., diodes 50). In one embodiment, the mesh 210 is a woven pattern of electrical conductors. The mesh 210 is itself relatively stiff, and the open portions are slightly smaller than the diameter of the diodes 50, so that when the diodes are pressed into the mesh, the mesh and diodes are relatively secured together. This eliminates the need for any external adhesive, such as solder or epoxy, although such adhesive can be used.

In addition to the mesh 210 and the diodes 50, the assembly 200 also includes a dimpled sheet 220. In one embodiment, the dimpled sheet is formed of aluminum foil, although other embodiments are anticipated. Aluminum foil is desirable because of its ability to reflect sunlight, discussed in greater detail below. The mesh 210 and diodes 50 are positioned with the sheet 220 so that there exists a first electrical contact between the mesh and one electrode of the diodes, and a second electrical contact between another electrode of the diodes and the sheet. It is desired that the mesh 210 and the sheet 220 are maintained in electrical isolation from each other, except through the diodes 50.

In operation, sunlight or other energy is provided to the diodes 50. The diodes convert the energy to electrical energy, which is provided to the mesh 210 and the sheet 220. Therefore, the mesh 210 and the sheet 220 act as electrodes for the entire assembly 200.

Referring specifically to Figs. 7a and 7b, as stated above, the sheet 220 is dimpled. The dimples can perform several functions according to different embodiments. In one embodiment, a concave dimple 222 is formed as a semi-circle to perform various functions. First of all, the concave dimple 222 allows one or more diodes 50 (one diode is illustrated) to be positioned "inside" the sheet 220. By being inside the sheet, the diode is protected from various external forces. In addition, the concave dimple 222 serves to direct sunlight (or other energy) towards the diode 50. As a result, sunlight can be applied to a majority of the diode's surface.

Positioned within the concave dimple 222 is a support structure 224. In the present embodiment, the support structure 224 is connected to the concave dimple 222 through one or more legs 226. The support structure 224 thereby centers the diode 50 in the concave

dimple 222, which allows even more sunlight to contact the diode's surface. The legs 226 also define an aperture 228 through which a fluid (e.g., rain water) and/or debris may flow. An advantage is provided by maximizing the reflected energy by removing fluid and/or debris.

5 Referring specifically to Fig. 7c, in one embodiment, a plurality of support dimples 240 can be used to support the sheet 220 and to provide extra rigidity. In the present embodiments, the support dimples 240 are positioned between the various concave dimples 222, but are not present along the outermost edges of the sheet 220. In other embodiments, different arrangements of the support dimples 240 can be provided, including placing the
10 dimples on the outermost edges of the sheet 220, to accommodate different desired applications. In some embodiments, the support dimples 240 include a plurality of apertures 242 through which a fluid (e.g., rain water) and/or debris may flow.

Referring to Figs. 8a-8c, the solar panel assembly 200 can be constructed in different ways, using one or more of the processes discussed below. The following processes are
15 discussed with reference to the spherical shaped solar diode 10 of Fig. 1. It is understood, however, that the diode 50 of Fig. 3 or any other solar detector device may be used, with adjustments made to accommodate the different device.

Referring specifically to Fig. 8a, the diode 10 is processed to reveal a portion of the p-type material 12 to an exterior contact. In one embodiment, the processing may be in the
20 form of a polishing operation, producing a flat surface 250, as shown.

Referring specifically to Fig. 8b, the exposed portion of the p-type material 12 is illustrated having a width (diameter) of $d1$. The support structure 224 of the sheet 220 is illustrated having a width of $d2$. In the present embodiment:

$$d2 < d1.$$

25 In some embodiments, the support structure may be relatively large, and have a special contact portion for electrically connecting to the diode 10.

Referring specifically to Fig. 8c, as a result, the diode 10 can rest on the support structure 224 so that the support structure only contacts the p-type material 12. Since the support structure 224 is relatively small, it does not electrically contact the n-type material
30 14.

Referring to Figs. 9-11, it may be desirable to locate and isolate bad detectors in the solar panel assembly 200. In the present example, a bad detector is a diode that is

electrically shorted. The shorts may be a result of various problems, such as poor construction of the diode itself, or improper mounting of the diode to the support structure 224. Electrically shorted diodes are harmful because they draw an excessive amount of current and may cause various electrical problems, which are well understood by those of ordinary skill in the art. While electrically open diodes are not operational and therefore do not provide solar power, individually they do not harm or otherwise damage the solar panel assembly 200.

Referring specifically to Fig. 9, one way to locate an electrically shorted diode is to provide an alternating current (AC) power supply 260 to the solar panel assembly 200. The AC power supply 260 connects to the sheet 220 and the mesh 210. For the sake of example, the solar panel assembly 200 includes a plurality of the diodes 10a, of which four are illustrated. All of the "good" diodes (properly operational) are labeled with the reference numeral 10a, the shorted diodes are labeled with the reference numeral 10a.1, and the open diodes are labeled with the reference numeral 10a.2.

Referring also to Fig. 10, as the AC power supply 260 provides an alternating current cycle to the diodes, the good diodes 10a perform differently from the bad diodes 10a.1, 10a.2. The good diodes 10a perform as indicated by graph 270, in that they are conducting for half of the cycle, and appear as open circuits during the other half. The shorted diodes 10a.1 perform as indicated by graph 272, in that they are conducting for the entire cycle. The open diodes 10a.2 perform as indicated by graph 274, in that they are not conducting for the entire cycle. It is well understood in the art that the shorted diodes 10a.1 will produce significantly more (e.g., twice as much) heat as the good diodes 10a, and the open diodes 10a.2 will produce almost no heat.

Referring now to Fig. 11, a thermal device 280 can be placed near the assembly 200 to detect one or more "hot spots." The hot spots identify where the shorted diodes 10a.1 are located. In the present example, there are two shorted diodes 10a.1 interspersed among the other diodes 10a and 10a.2 on the assembly 200. Two hot spots 282, 284 are detected by the thermal device 280, accordingly. It is understood that in the present embodiment, the two hot spots 282, 284 are simultaneously detected. However, in other embodiments, the assembly 200 may be larger than the thermal device 280, so that one is moved relative to the other to detect all of the hot spots.

Once the hot spots 282, 284 are detected, the shorted diodes 10a.1 can be readily identified and disabled. Additional tests can be performed on the assembly to determine if an acceptable number of good diodes 10a are present in the assembly, or for other functional requirements.

5 While the invention has been particularly shown and described with reference to the preferred embodiment thereof, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention, as set forth in the following claims.

Claims

WHAT IS CLAIMED IS:

1. A non-planar solar diode comprising:
a first substrate of a first material being either n-type or p-type;
5 a second layer of a second material being a different type than the first material, the second layer surrounding the first layer; and
a plurality of hetero-junction super lattice structures surrounding the second layer.
2. The diode of claim 1 wherein the plurality of hetero-junction super lattice structures
10 includes alternating layers of Si and SeBeTe.
3. The diode of claim 2 wherein an elemental ratio of SeBeTe is 1:0.55:0.45.
4. The diode of claim 1 wherein the plurality of hetero-junction super lattice structures
15 are formed by chemical vapor deposition.
5. The diode of claim 1 wherein the plurality of hetero-junction super lattice structures adapt the diode to convert higher energy light (as compared to 1.1eV light) to electrical
energy.
20
6. The diode of claim 1 wherein the first material is spherical shaped and the second material covers a majority of the first material.
7. The diode of claim 6 wherein a relatively small portion of the first material is not
25 covered by the second material.
8. A solar panel assembly comprising:
a plurality of solar devices, each device having two electrodes;
a wire mesh for securing the devices and electrically contacting one electrode of each
30 device;
a dimpled sheet for securing the devices and electrically contacting the other electrode of each device;

wherein, the devices are positioned adjacent to the dimpled sheet so that when light is applied to the solar panel assembly, the devices are exposed to the light on a majority of each device's surface.

5 9. The solar panel assembly of claim 8 wherein the dimpled sheet includes a plurality of concave dimples, one for each device, each concave dimple for individually reflecting light to the corresponding device.

10 10. The solar panel assembly of claim 9 wherein the concave dimples are also formed to protect the corresponding device from external forces.

15 11. The solar panel assembly of claim 9 wherein each concave dimple includes a support structure for positioning each corresponding device in a central interior portion of the concave dimple.

20 12. The solar panel assembly of claim 11 wherein each device is mostly spherical in shape, with an outer portion for providing one electrode and an exposed inner portion for providing another electrode having a first width $d1$, and wherein each support structure has a second width $d2$ such that $d1 > d2$.

25 13. The solar panel assembly of claim 9 wherein each concave dimple includes an aperture through which a fluid may flow.

30 14. The solar panel assembly of claim 8 wherein the dimpled sheet includes a plurality of support dimples for strengthening and supporting the assembly.

15. The solar panel assembly of claim 14 wherein each support dimple includes an aperture through which a fluid may flow.

36 16. The solar panel assembly of claim 8 wherein the solar devices are spherical shaped diodes, each diode comprising:
a first substrate of a first material being either n-type or p-type;

a second layer of a second material being a different type than the first material, the second layer surrounding the first layer; and

a plurality of hetero-junction super lattice structures surrounding the second layer.

- 5 17. The solar panel assembly of claim 16 wherein the plurality of hetero-junction super lattice structures includes alternating layers of Si and SeBeTe.

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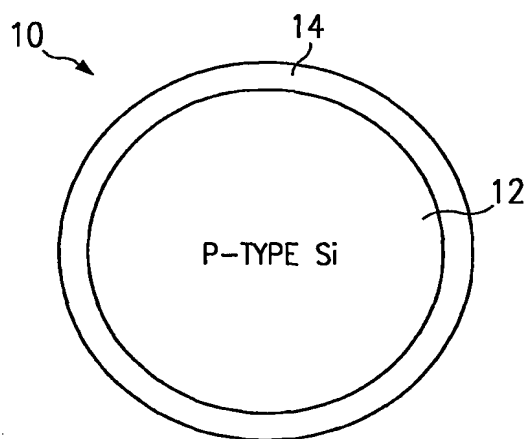


Fig. 1

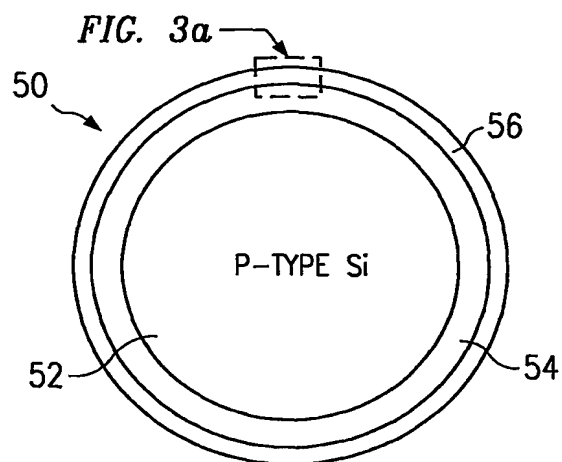


Fig. 3

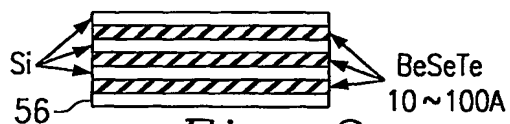


Fig. 3a

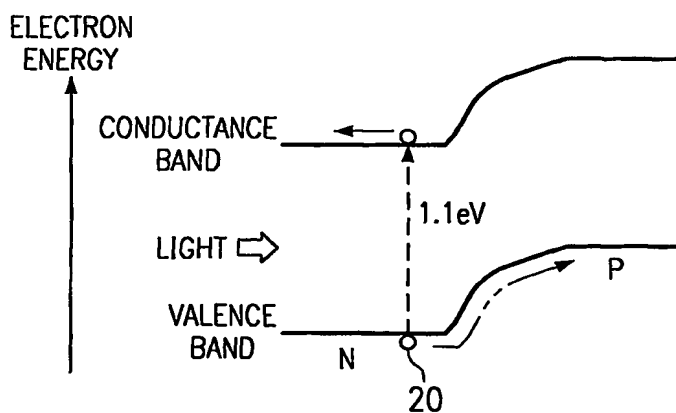


Fig. 2a

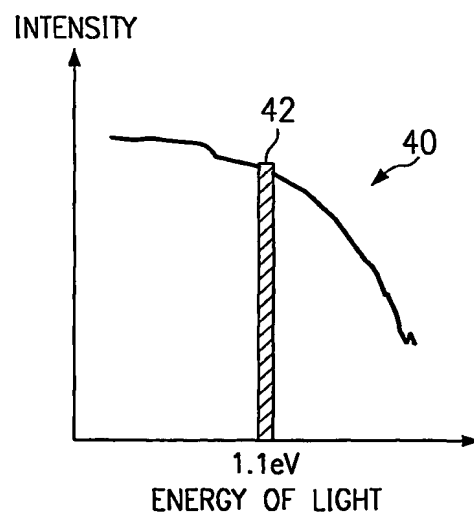
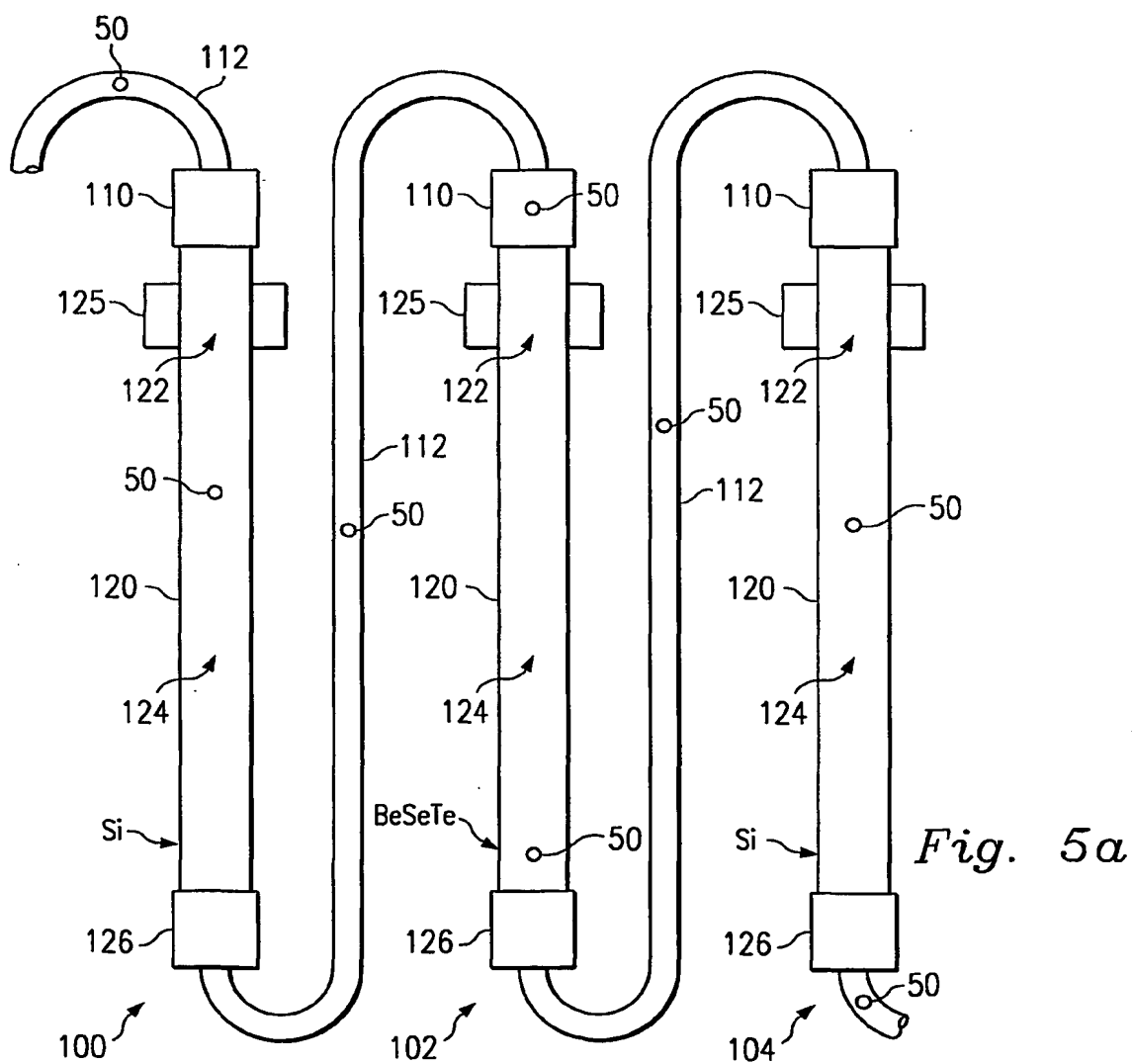
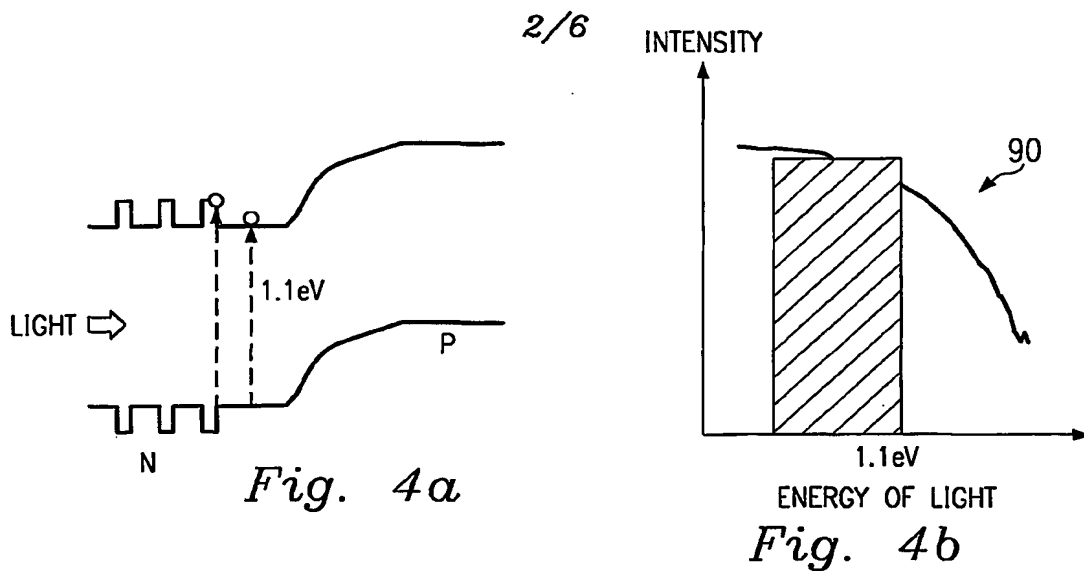
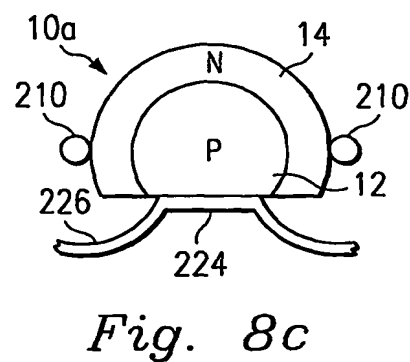
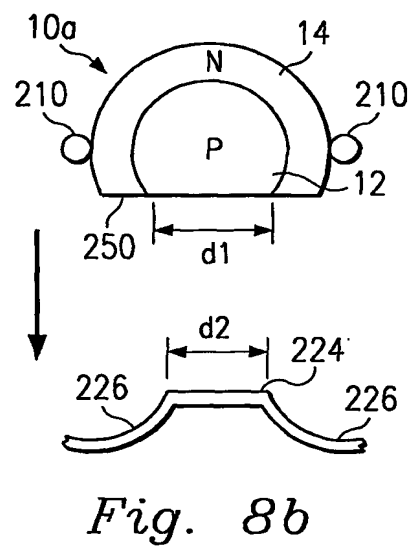
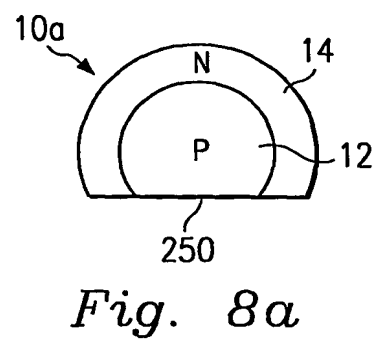
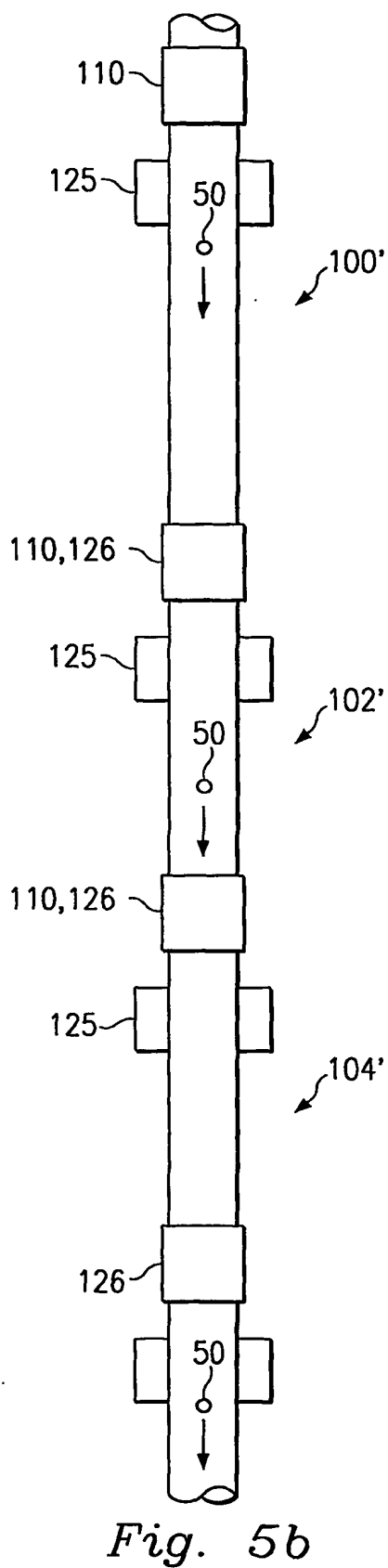
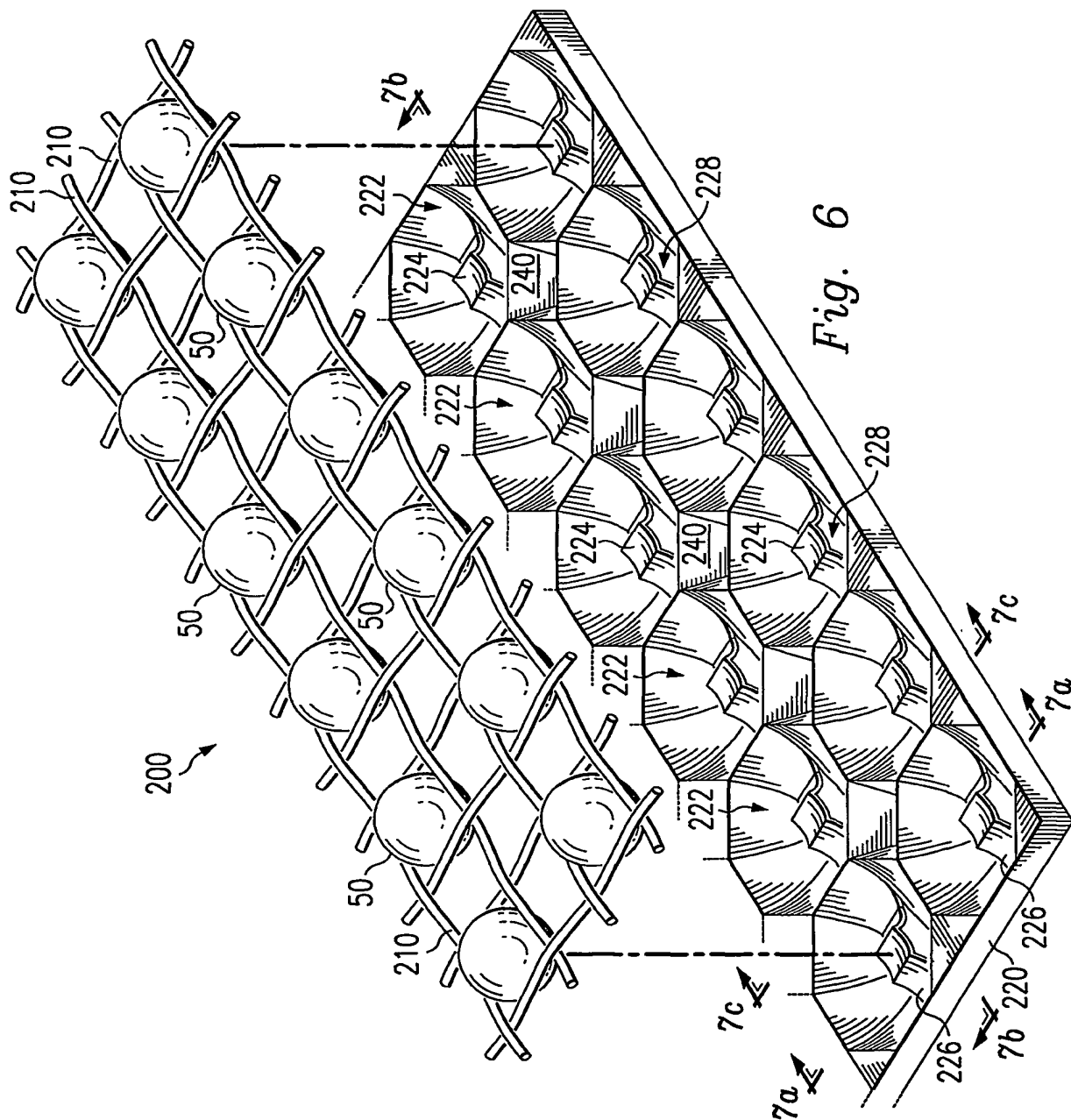


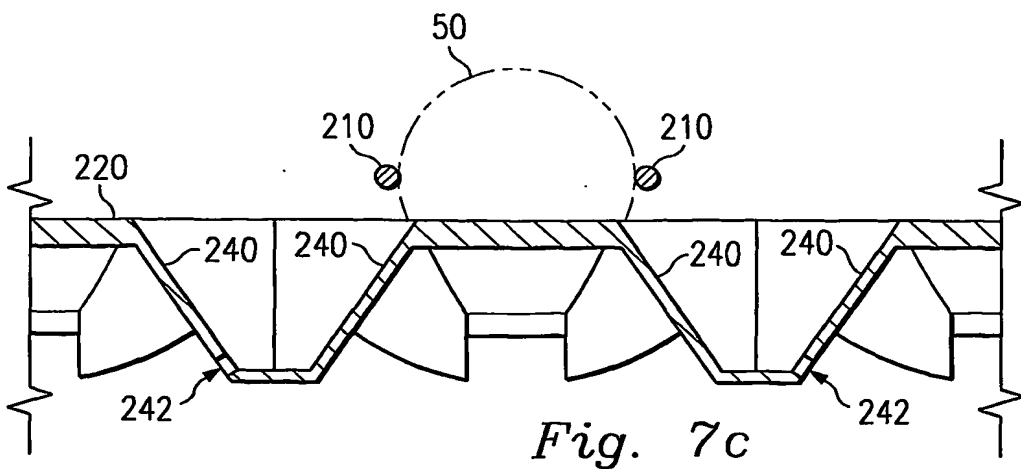
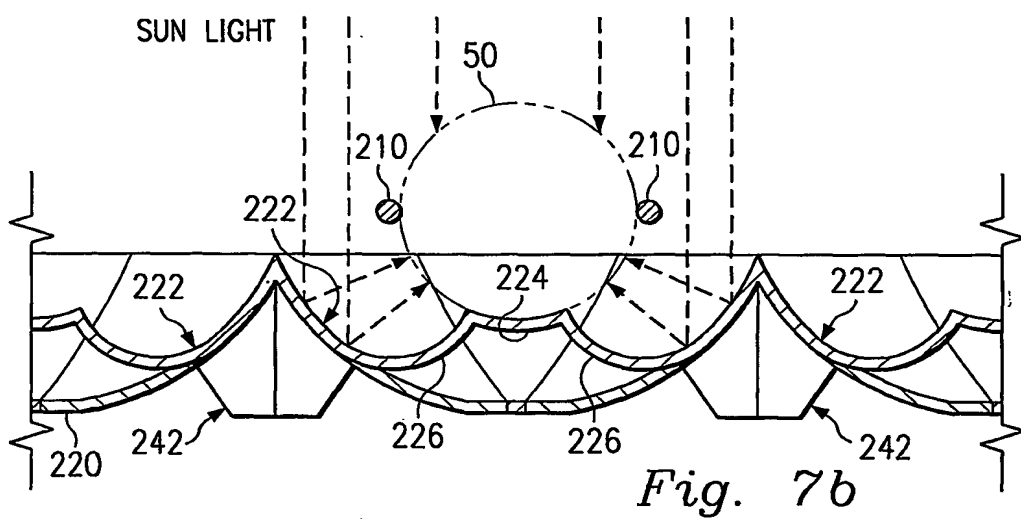
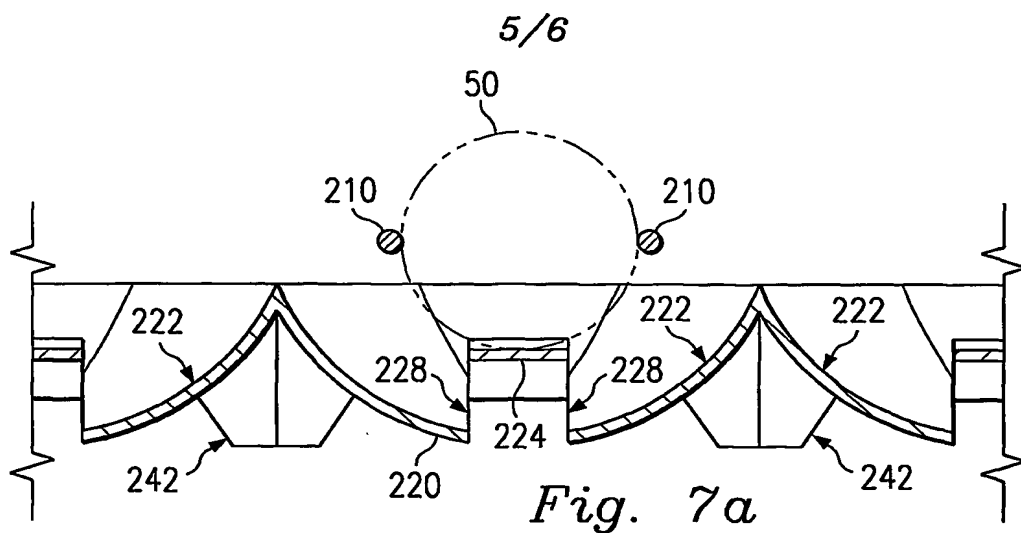
Fig. 2b



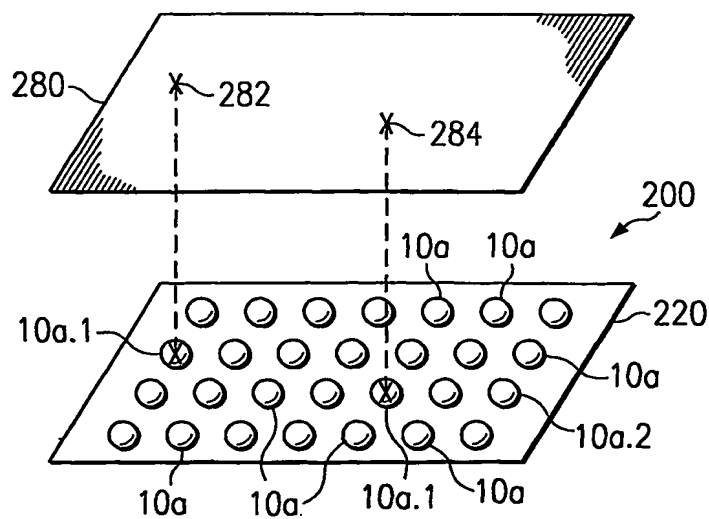
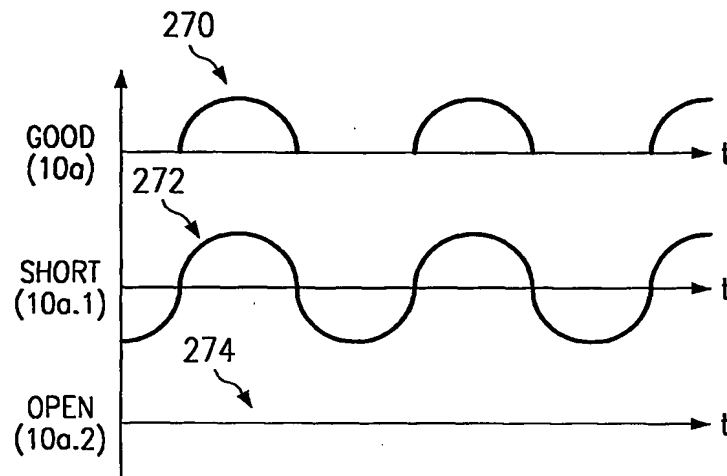
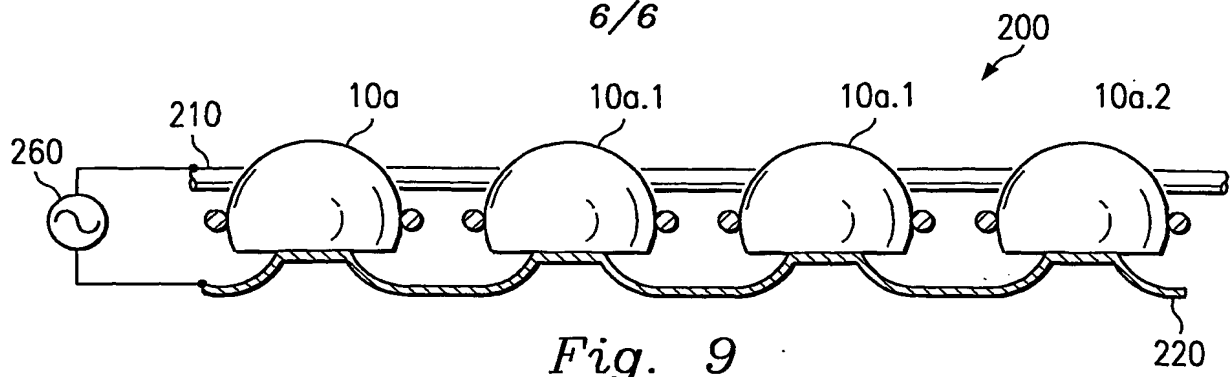
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/16581

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : H01L 31/0272, 31/0352, 31/072

US CL : 136/244, 250, 249, 255, 261, 264; 257/443, 459, 461, 465

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 136/244, 250, 249, 255, 261, 264; 257/443, 459, 461, 465; 438/63

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3,171,068 A (DENKEWALTER et al) 23 February 1965 (23.02.1965), column 3, lines 7-18, and Figure 1.	1, 4, 5
A		2, 3, 6-17
A	245 3,172,791 A (ALLEGRETTI et al) 09 March 1965 (09.03.1965).	1-17
A	US 4,407,320 A (LEVINE) 04 October 1983 (04.10.1983).	1-17
A	45 4,913,744 A (HOEGL et al) 03 April 1990 (03.04.1990).	1-17
A	US 5,902,416 A (KERN et al) 11 May 1999 (05.11.1999).	1-17
A	US 5,437,736 A (COLE) 01 August 1995 (01.08.1995).	1-17
A,P	US 6,204,545 B1 (NAKATA) 20 March 2001 (20.03.2001).	1-17

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

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Date of the actual completion of the international search

03 July 2001 (03.07.2001)

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